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Modelling of the Hydrological and Soil Erosion Processes Under Climate Change and Land Use Pattern of the Lake Tana Basin, Ethiopia* by *Geospatial Technology

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Modelling of the Hydrological and Soil Erosion Processes Under Climate Change and Land Use Pattern of the Lake Tana Basin, Ethiopia* by *Geospatial Technology

Chapter 1: Introduction

This chapter includes a background of the study, statement of the problem, study objectives, significance, scope, and limitations.

1.1. Background of the study

Since the industrial revolution began in the mid-eighteenth century, human activity has increased greenhouse gas (GHG) concentrations in the atmosphere dramatically, causing climate change (Gebresilassie 2020).The burning of fossil fuels has contributed two-thirds of manmade CO_2 emissions since 1750, while land use change is responsible for one-third (Toulmin 2009). The concentration of carbon dioxide has increased by 40% since pre-industrial times, primarily because of fossil fuel burning and secondarily because of net land use change emissions.

More than half of the global average surface temperature rise between 1951 to 2010 was most certainly caused by human-caused GHGs (IPCC, 2014). Future climate will depend on committed warming caused by past anthropogenic emissions, future anthropogenic emissions, and natural climate variability. Under RCP8.5 Radiative forcing scenarios, the global mean surface temperature increased by 2.6°C to 4.8°C by the end of the twenty-first century (2081–2100) compared to 1986–2005 (IPCC, 2014).

Climate change poses a significant threat to sustainable development. It creates several interconnected problems, including water scarcity, increased food production constraints, and health and disaster hazards (UNESCO, 2013). Despite contributing less than 4% of global GHG emissions (IPCC, 2007), climate change and variability have substantially impacted Africa (Gebresilassie, 2020). The temperature projected in Africa increased higher than the global average in the 21st century (IPCC, 2013).

Ethiopia has an enormous water resource potential that includes eleven major lakes with a total area of 7,400 Km^2, twelve river basins with a total annual surface runoff of about

110 billion $m^{3,}$ and groundwater with an estimated capacity of 2.56 billion m^3. Most rivers are transboundary, with more than 75% of the annual surface runoff draining to neighbouring countries (Awulachew et al., 2008).

Because of its long history and service to over 238 million people in eleven nations, the Blue Nile River (BNR) is the most well-known transboundary river (Melesse et al., 2014). The BNR is responsible for 82% of the Nile flow with the Tekeze and Baro-Akobo rivers. It is gradually decreasing due to population pressure in hydrologically sensitive areas, land degradation, upstream water diversion for irrigation and hydropower production, and changes in rainfall patterns (distribution, quantity, and timing).The Nile River Basin has diverse rainfall patterns and climate that varies spatially and temporally. Climate change raises the demand for water while decreasing the supply (availability). One of the rivers significantly impacted by climate change is the BNR(Gelete et al., 2019).

Climate change due to greenhouse gas (GHG) emissions are impacting the global hydrological cycle and regional hydrology worldwide and will continue in the future (Sohom et al., 2017). The hydrological cycle is significantly influenced by temperature and rainfall parameters. Changes in temperature and precipitation are already having significant impacts on ecosystems, agriculture, and water resources activities and will magnify them in the future (Hassan et al., 2014; Sohom et al., 2017)(Gosling & Arnell, 2016)suggested that water shortages are projected to expand significantly due to rising human pressure on water supplies even in the absence of climate change. Landuse changes modify the characteristics of runoff, percolation, groundwater recharge, sediment yield, and evapotranspiration. By altering the hydrologic cycle, land use/ land cover (LULC) could increase hydrological variability (Gashaw et al., 2019; Gebremicael et al., 2019).

Nevertheless, the impact of climate and LULC change on hydrological systems are still little understood. For instance, land-use change may exacerbate or reduce the effects of climate change on the hydrological processes. As a result, the combined effects of climate and LULC changes on the hydrological processes must be further investigated.

1.2. Area of investigation

This synopsis is about the PhD thesis on modelling hydrology and erosion processes under changing climate and land use in the Lake Tana basin of the upper Blue Nile River Basin (BNRB), Ethiopia. The total area in the Lake Tana basin, including the lake area, is around 15096 km^2 (Figure 1). Geographically, the study area is located between $10^0$55 'to $12^0$45' N latitude and $36^0$40' to $38^0$20' E longitude. The Lake Tana basin has remarkable national significance. It encompasses high irrigation potential, such as Fogara and Debian plain, Tiss Abay and Tana Beles hydroelectric power generation, high-value crops, especially cash crops and livestock production, and ecotourism.

Lake Tana, a natural reservoir located in this basin, is the main source of the BNR. It is approximately 84 km long, and 66 km wide and is situated in the northwestern highlands of the country. The lake is a natural freshwater lake covering an area of 3000 - 3600 km^2 at an altitude of 1784 m. The highland and shallow lake is Lake Tana, it has a depth of 15 m. The Gilgal Abay, Gumera, Ribb, and Megech rivers are the major tributaries of Lake Tana. Gilgel Abay and Megech River have the highest and lowest mean monthly streamflow.

The present study shows that more than 93 % of the annual lake water budget is contributed to these four inflow rivers. The annual flow volume of 4 billion (m^3/year) for the Blue Nile (Abay) river is measured at the Bahir Dar gauging station. Furthermore, Lake Tana outflows made up 8.1% of the total Blue Nile Rosaries and were generated from 8.7% of the total catchment area (Conway, 2000).

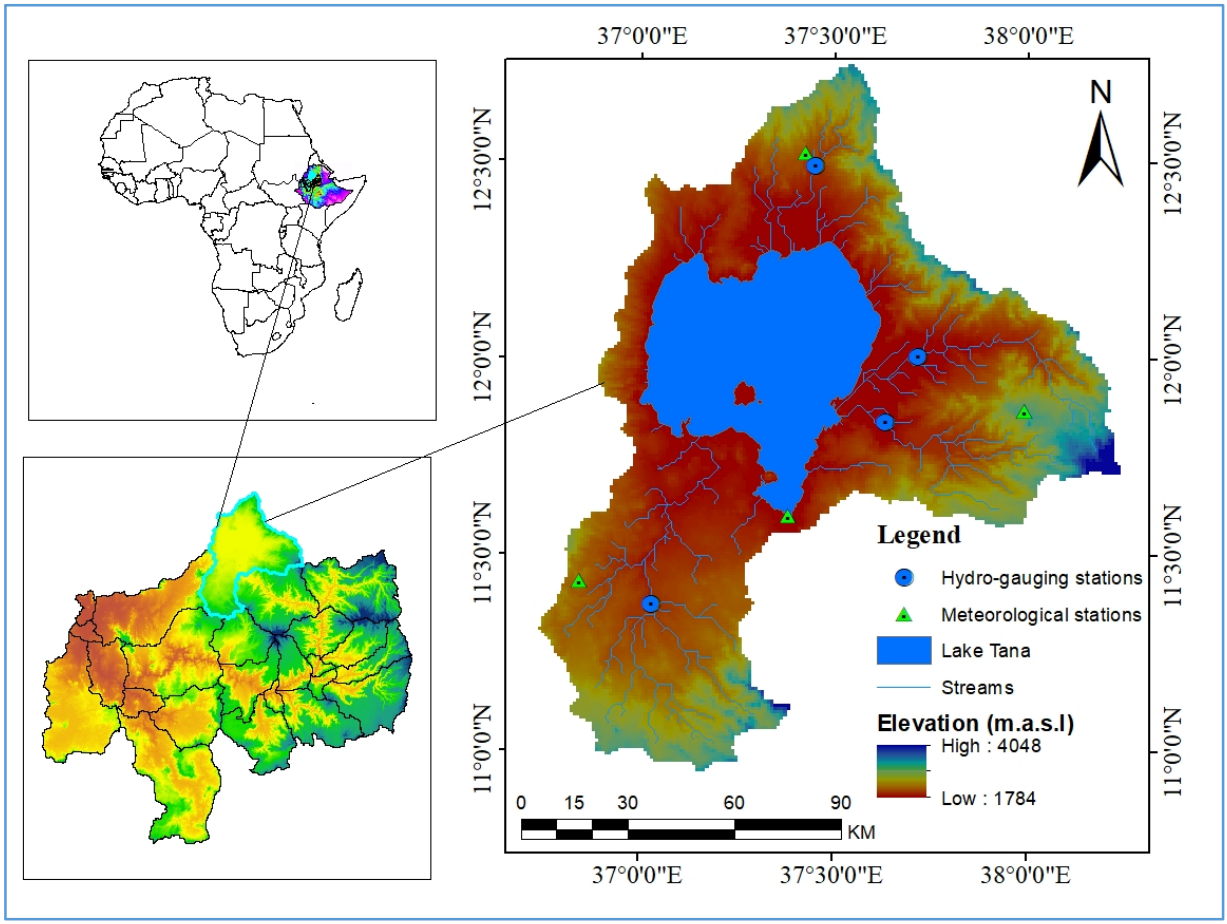

Figure 1. Map of the study area

1.3. Statement of the problem

The Lake Tana basin is the most intensively utilized basin and has tremendous potential for irrigation, hydropower, and other development activities. In spite of that, the Lake Tana basin has been degraded due to inappropriate and mismanagement of land use (Bogale 2020). The Lake Tana basin is experiencing significant soil degradation, sedimentation, and degradation of land (Setegn et al., 2009; Stave et al., 2017). Losing topsoil in the basin greatly impacts agricultural yields. In addition, soil sediment deposition in Lake Tana disrupts ecosystem services as well. The hydrology of the basin is substantially affected by climate change.

Yet, hydrological and soil erosion are not fully understood as a result of climate change and land use change.The majority of past studies have assessed either the impacts of

climate change (Legesse et al. 2003; Woldesenbet et al. 2018; Dibaba et al. 2020; Berihun et al. 2019) in the Lake Tana basin and other basins of Ethiopia (Awotwi et al. 2017; Joorabian et al. 2017; Kim et al. 2013; Pijl et al. 2018; Aduah et al. 2017) or impacts of land use change studies (Chen et al. 2019; Derdour et al. 2018; Deribew and Dalacho 2019; Yesuf et al. 2008; Kaushal et al. 2017; Li et al. 2018a). Moreover, they assessed only hydrological processes and soil erosion in the basin.

In addition, many previous studies investigated either the impact of climate change on hydrological processes or the impact of LULC change on the hydrology and soil loss of the Lake Tana basin. Furthermore, those studies used only future climate projections while ignoring the impacts of land use change. However, this study examined the combined and separate impacts of climate and land use change on hydrological processes and soil loss in the future.

The combined effects of changing land use and climate on water availability are influenced by the rapidly increasing population. This negatively impacts the food, water, and energy security of nations. In this respect, assessing the basin's hydrological response is critical for the development and implementation of a management plan that ensures sustainable water resource production.

Assessing the impacts of environmental change caused by land use and climate is vital for developing sound environmental policies. Knowing the past/historical change in climate and LULC on the water balance component is, therefore, necessary to properly predict the future. The key to developing and implementing long-term water and land management strategies is to recognize the individual and integrated effects of LULC and climate on hydrology components. Consequently, the study looks at the response of the Lake Tana basin's hydrological balance to the separate and combined effects of changes in LULC and climate. Therefore, this study uses land use-land cover models, climate prediction, climate downscaling, and hydrological models to simulate the combined effects of future climate change and land use change on hydrological response.

1.4. Objectives of the study

This study focuses on modelling hydrological and erosion processes in the Lake Tana basin under climate and land use change. Its specific objectives were:

- To detect and simulate land use and land cover change in the study area.
- To downscale climate change projections based on statistical downscaling.
- To assess the separate impacts of climate change and land use change on hydrologic processes.
- To quantify the combined effects of land use/cover and climate change on hydrological processes.
- To estimate soil erosion through the integration of remote sensing and geographic information systems.

1.5. Organization of the study

The study is organized into five chapters. In the first chapter, you will find the introductory part, which covers the background of the study, the statement of the problem, the objectives, significance, scope, and limitations of the study. The second chapter reviewed literature related to the study's main goals of the study. The third chapter presented the materials and methods of the research. The fourth chapter dealt with the results and a discussion of the study. Chapter five provides conclusions and recommendations for the study

Chapter 2: Review of related literature

A review of related literature is presented in this chapter. This section discusses climate change, the causes of climate change, climate change scenarios, and the Ethiopian climate. Furthermore, climate change models, land-use change models, and empirical studies related to separate and combined impacts of climate and land-use change on hydrology and erosion processes, as well as hydrological models, are incorporated into this chapter.

Chapter 3: Materials and Methods

The study's objectives were achieved by utilizing different data sources and data analysis techniques.

3.1. Datasets

Land use/ land cover data were obtained fromLandsat 4-5 Thematic Mapper (TM) in 1989, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) in 2005, and Landsat 8 Operational Land Inventory (OLI) in 2019. The Landsat data has been used for land use/land cover classification purposes.Ground controlling point (GCP) data was also used for accuracy assessment.The 30-meter Shuttle Radar Topographic Mission (SRTM) satellite data digital elevation model (DEM) obtained from the National Aeronautics and Space Administration (NASA) website https://dwtkns.com/srtm30m/ was used. The DEM data was used to define the watershed boundary, sub-watersheds, hydrological response units, and slope reclassification.

The soil data obtained from the Ministry of Agriculture (MOA) was also used. Furthermore,baseline climate data from 1975 to 2019 and downscaled data from Climate Model Intercomparison Project Phase five (CMIP5) model CanESM2 GCM global circulation models (GCMs) were also employed for the study. Finally, discharge data from four major rivers of the basin were collected from the Ministry of Water, Irrigation, and Electricity of Ethiopia, the Abay Basin Development office.

3.2. Methodology

3.2.1. Land use/land cover map preparation

Digital image analysis and visual image interpretation were performed after successfully downloading Landsat satellite data. Several image processing steps are performed before land use classification, including georeferencing, radiometric and atmospheric corrections, image enhancement, band composites, mosaicking, and subsetting. Then, supervised classification using Mahalanobis distance algorithms was applied to the study area. Furthermore, we evaluated the accuracy of the classified map with ground control points (GCP) using the kappa index of agreement.

3.2.2. Land use/land cover projection

On the basis of the baseline LULC map of 1989, 2005, and 2019, future simulations of LULC for the 2040s, 2070s, and 2100 were conducted. A constraint and factor map for future simulation maps was also prepared. Following the preparation of constraint and

factor maps, Multi-Criteria Evaluation (MCE)-Weighted Linear Combination (WLC) decision support techniques were used to prepare each LULC class. LULC simulations were then produced using the CA_Markov Chain model. In order to determine the accuracy of the LULC map of the basin, the model was validated. Using cross-tabulation analysis, a simulated map of 2019 was compared with a baseline map produced using supervised classification.

3.2.3. Climate change projection and trend analysis

A statistical downscaling model (SDSM) was used to fit the CMIP5 model of CanESM2 GCM data to basin-scale hydrological modelling. In this study, the accuracy of downscaling was assessed using baseline data from 1975 to 2019 as well as reanalysis data from the National Center for Environmental Prediction (NCEP) between 1961 and 2005. A total of 26 large-scale atmospheric variables exist. Statistical relationships between these large-scale atmospheric variables and locale-scale atmospheric variables were then established. Quantitative statistics were used to evaluate the downscaling performance, including the correlation coefficient (r), coefficient of determination (R2), Root Mean Square Error (RMSE), and Nash Sutcliffe Efficiency (NSE). Furthermore, both temperature and precipitation trends were detected by the Mann-Kendall non-parametric test.

3.2.4. Hydrological model using Soil and Water Assessment Tool (SWAT) model

SWAT is a conceptual or operational model that operates daily. In broad ungagged basins, the SWAT model predicts the effects of land management strategies on chemical yields, sediment, and water. It is possible to simulate actual evapotranspiration, potential evapotranspiration, percolation, surface flow, lateral flow, groundwater flow, and total water yield using the SWAT model. To run the model, all input parameters were used, including LULC, soil, and weather data. Model performance was assessed using NSE, correlation coefficient (R2), and percent of bias (PBIAS). The observed discharge data is compared to the simulated model output data during the calibration and validation stages. Therefore, Integrated Parameter Estimation and Uncertainty Analysis Tool (IPEAT) was used to assess the sensitivity analysis, calibration, and validation of the model performance. The model was run using QGIS Plugin SWAT+ software.

3.2.5. Soil erosion modelling using the Revised Universal Soil Loss Equation (RUSLE)

The erosion of soil by water is one of the most significant causes of soil erosion over time (Mohamed et al., 2022). It is possible to compute the mean annual loss of soil for any location by applying RUSLE (Revised Universal Soil Loss Equation) involving six parameters (Wischmeier & Smith, 1978), where each parameter can be expressed mathematically (Mengistu et al., 2015). Therefore, these six parameters are rainfall erosivity (R), soil erodibility (K), topography (LS), cover and management (C), and support and conservation practices (P). They were calculated from soil, baseline and projected rainfall data, DEM, and baseline and simulated LULC data using ArcGIS software. In addition, a raster calculator in the ArcGIS environment has been used to overlay all these parameters and estimate soil loss per hectare per year.

Chapter 4: Results and Discussion

4.1. Land use change detection

The kappa coefficient and user accuracies were 85.7% and 87% for the 2005 LULC and 89.3% and 90.8% for the 2019 LULC, respectively. (Anderson et al., 1976) stated that a kappa coefficient of more than 85% is acceptable. There is an agreement between ground truth and classified classes. The maps generally met the requirements of minimum accuracy assessment in following post-classification activities, such as detection of change and SWAT model input. Following this, the basin is divided into seven categories of LULC: farmland, built-up areas, forest land, water bodies, shrublands, bare lands, and grasslands. The past 30 years have seen an increase in farmland, built-up areas, and forests, while decreasing water bodies, shrublands, barren lands, and grasslands.

4.2 Land use and land cover simulation

The LULC change simulation was validated using the 2019 baseline LULC maps of the study area. Various Kappa Indices of Agreement (KIA) K standards and respective statistics indicate the agreement between baseline and projected maps. The kappa statistics such as K standard= 0.81, Kno= 0.87, and K location= 0.88 were obtained in

the validation process, indicating good agreement between the projected and baseline map. Like the historical land use of the study area, there is a similar pattern of change in simulated land use for the 2040s, 2070s, and 2100s.

4.3. Climate change projection

P-values and partial correlations are used to select the best predictor variables for the model. For all stations, the mean sea level pressure, mean temperature at 2 m, surface specific humidity, and temperature at 2 m were the dominant predictor variables. For precipitation, the most common predictor variables at all stations were surface-specific humidity, mean temperature at 2 m, 850hpa vorticity, and 1000hpa zonal velocity. Compared to precipitation, the SDSM performed well in downscaling maximum and minimum temperatures.

4.3.1. Projection of maximum, minimum temperature, and precipitation

For comparison purposes, the future period is divided into three-time slices, namely, the 2020s (2011-2040), 2050s (2051-2070), and 2080s (2071-2100) compared to baseline data from 1981 to 2010.The maximum and minimum temperatures of the Lake Tana Basin (LTB) are projected to increase at various rates in three-time slices according to different Radiative forcing scenarios (RCPs). Under RCP8.5 radiative forcing scenarios, for example, the maximum temperature increased by 2.46^0C by 2080, whereas the minimum temperature increased by 5.9^0C. However, precipitation projections are uncertain. Depending on the scenario, the annual precipitation pattern in the basin is projected to increase in the northern and central parts while decreasing in the southwest and eastern parts.

4.3.2. Trend analysis of maximum, minimum temperature, and precipitation

In the basin, both the baseline and the projected maximum and minimum temperatures show an increase, and statistically significant trends have been observed and projected as well. In contrast, the basin's selected stations show inconsistent rainfall trends. Under RCP8.5 radiative forcing scenarios, Bahir Dar is expected to see rain increase by 3.2mm/yr, while Gonder will see rain increase by 1.2mm/yr. However, precipitation is expected to decrease by -2.3mm/yr at Dangila and -1.2mm/yr at Debre Tabor under

RCP8.5 radiative forcing scenarios. This may occur because of climate model problems and the quality of input data used by the model.

4.4. Hydrological model

4.4.1. Calibration and validation of SWAT model

The model has been calibrated and validated using discharge data from four major rivers in the basin from 1980 to 2007. To warm up the model, five years of observed streamflow data from 1980 to 1984 have been used. Then, fifteen years of data (1985-1999) were used for calibration, and eight years of data (2000-2007) were used to validate the model. In the calibration and validation of the model, the most sensitive parameters were CN2, ESCO, AWC, ALPHA, DELAY, FLOW_MIN, REVAL_CO, and REVAL_MIN. In comparison with Megech and Ribb River watersheds, Gilgel Abay and Gumera watersheds performed relatively well during calibration and validation. Then, three simulation scenarios were developed to examine LULC and climate change impacts separately and together.

4.4.2. Historical land-use change impacts the hydrology of the basin

A comparison of the hydrological components changes three-time slices in 1989, 2005, and 2019 was conducted. During the study period, surface runoff and water yield increased while evapotranspiration and baseflow decreased. The primary cause of the basin's increased surface runoff and water yield is the expansion of farmland.

4.4.3. Future simulated LULC change impacts on the hydrology of the basin

The simulated LULC changes typically result in lower streamflow than the baseline. Under future LULC simulation scenarios, the mean seasonal evapotranspiration changes in the Lake Tana basin decreased. Both streamflow and lateral flow decrease during the wet season (JJAS) months, while rising during the dry season (ONDJF) and the small rainy season (MAM). There is a direct correlation between streamflow and lateral flow in the basin and the expected shift in precipitation.

4.4.4. Future climate change impacts on the hydrology of the basin

Climate change alone is likely to lead to higher evapotranspiration due to an increase in maximum and minimum temperatures and an increase in forest cover in the basin. In all seasons, the lateral flow will increase, but the amount of change will vary depending on the season. Due to the highly spatial-temporal variation of rainfall in the basin, streamflow did not follow a consistent pattern under all periods and scenarios. Streamflow would likely decrease under the RCP8.5 scenario during the dry and main rainy seasons while increasing during the small rainy season.

4.4.5. Combined impacts of climate and land-use change on the hydrology of the basin

In this scenario, climate change and land use change were integrated to examine the hydrology of the basin. There are similar patterns of change in evapotranspiration, lateral flow, and streamflow when climate change alone is considered. However, the rate of change is smaller than a separate climate, and only LULC impact is considered.

4.4.6.Soil erosion under climate, land use and land cover, and combined climate and land use and land cover change

The baseline R factor ranges from 534 to 923 MJ mm ha^{-1} h^{-1} y^{-1}. Under RCPs (2.6, 4.5, and 8.5) scenarios, the R factor ranges in the 2020s from 623.2 to 860.5 MJ mm ha^{-1} h^{-1} y^{-1}, while in the 2050s and 2080s it ranges from 637.7 to 838.6 MJ mm ha^{-1} h^{-1} y^{-1} and 648.6 to 855.4 MJ mm ha^{-1} h^{-1} y^{-1}, respectively.

It is estimated that between 1981 and 2019, the basin had a mean erosion rate of 7.7 tons/hectare/year. Based on the estimated mean annual soil loss, the basin is divided into six severity classes. As a result, only 3.6% of the area encountered moderate to severe erosion, with annual losses exceeding 50 tons per hectare.

As a result of climate change, erosion rates are higher than when LULC and climate change impacts are considered together. By the end of the 21st century, erosion is

projected to increase by 11.6% due to climate change, 2.3% due to land change and 2.6% due to combined climate and land change.

Based on mean annual soil erosion, the basin is divided into 17 sub-watersheds to provide effective watershed management. The severity of soil erosion allows this sub-watershed to be classified into three priority classes. Therefore, the priority for watershed management should be sub-watersheds 1, 8, 10, 12, and 14, then sub-watersheds 3, 6, and 7. Sub-watersheds 2, 4, 5, 9, 11, 13, 15, 16, and 17 require third-level priority.

Chapter 5: Conclusion and Recommendations

5.1. Conclusion

The purpose of this study was to investigate the separate and combined effects of climate and land use change on the hydrology and erosion of the Lake Tana basin. A hydrological and soil erosion assessment of the Lake Tana basin was conducted using LULC projections, climate change downscaling, and SWAT modelling. A parametric and non-parametric statistical test was used to analyze trends in annual rainfall and temperature patterns over time. The climate change downscaling was done using SDSM, while the future LULC simulation was carried out using the Cellular Automata-Markov Chain model. LULC and climate change effects on hydrology and erosion of the Lake Tana basin were modelled using (SWAT) and RUSLE models.

Historical and simulated LULC change indicate built-up lands and farmland are increasing in the basin, while water bodies, grasslands, shrublands, and bare lands are decreasing. Baseline and projected temperatures of the basin also show an increasing trend. However, baseline and projected precipitation show no clear direction. The effects of climate change on water balance components and erosion of soil alone are more influential than changes in the LULC and the combined impacts of climate change and change in the LULC. Water balance components and soil erosion, for example, would be more susceptible to climate change than the LULC alterations scenario are considered.

5.2. Recommendations

Most of the basin's economy is based on small-scale irrigation and rainfed agriculture. A small change in rainfall would have a huge impact on agriculture and crop production. Therefore, the projected temperature rise (increase in maximum and minimum) would significantly impact agriculture, water, energy, and other sectors. To minimize the negative impacts of climate change, climate change adaptation and mitigation strategies should be developed at the basin or watershed scale.

The SWAT simulations performed well in the impact assessments of the separate and combined effects of LULC and climate in the Lake Tana basin. While the research considered separate and combined impacts of climate and LULC change on Lake Tana basin hydrology using a single GCM (CanESM2) CMIP5. A series of GCM experiments and a hydrological model are needed to assess the full extent of climate change effects. The GCM ensemble of the latest models, such as Climate Model Intercomparison Project Phase 6 (CMIP6), reduces model uncertainty in hydrological responses. Furthermore, the available hydroclimatic data of the basin should be improved to gain a better understanding of the impact of changes in the present and future land use and land cover on hydrological processes.

Nevertheless, this study provides valuable information on the relative influence of LULC and climate change on the hydrological basin process in the Lake Tana basin. In general, the results indicate that water resource management must take into account both climate and LULC changes. To reduce the impact of rapid climate change on the river basin, climate-resilient management strategies must be implemented.

References

Awulachew, S. B., McCartney, M., Steenhuis, T. S., & Ahmed, A. A. (2008). A review of hydrology, sediment and water resource use in the Blue Nile Basin. Colombo, Sri Lanka: International Water Management Institute. 87p. (IWMI Working Paper 131).

Conway, D. (2000). The Climate and Hydrology of the Upper Blue Nile River. *The Geographical Journal*, *166*(1), 49–62.

Gashaw, T., Tulu, T., Argaw, M., & Worqlul, A. W. (2019). Modeling the impacts of land use–land cover changes on soil erosion and sediment yield in the Andassa watershed, upper Blue Nile basin, Ethiopia. *Environmental Earth Sciences*, *78*(24). https://doi.org/10.1007/s12665-019-8726-x

Gebremicael, T. G., Mohamed, Y. A., & van der Zaag, P. (2019). Attributing the hydrological impact of different land use types and their long-term dynamics through combining parsimonious hydrological modelling, alteration analysis and PLSR analysis. *The Science of the Total Environment*, *660*, 1155–1167. https://doi.org/10.1016/j.scitotenv.2019.01.085

Gebresilassie, A. T. (2020). *Modeling the Impact of Climate and Land Use/Land Cover Change on Hydrological Responses in Lake Tana Basin, Ethiopia, A Dissertation Submitted to Ethiopian Institute of Water Resources.*

Gelete, G., Gokcekus, H., & Gichamo, T. (2019). Impact of climate change on the hydrology of Blue Nile basin, Ethiopia: A review. InJournal of Water and Climate Change. DOI: 10.2166/wcc.2019.014.

Gosling, S. N., & Arnell, N. W. (2016). A global assessment of the impact of climate change on water scarcity. InClimatic Change 134 (3), pp. 371–385. DOI: 10.1007/s10584-013-0853-x.

Hassan, Z., Shamsudin, S., & Harun, S. (2014). Application of SDSM and LARS-WG for simulating and downscaling of rainfall and temperature. InTheor Appl Climatol 116 (1-2), pp. 243–257. DOI: 10.1007/s00704-013-0951-8.

IPCC (2007). Climate change 2007. Impacts, adaptation and vulnerability contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge U.K., New York.

IPCC (2013). Summary for Policymakers. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom; New York, New York, USA.

IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. Ipcc, Geneva, Switzerland, 151 pp.

Melesse, A. M., Abtew, W., & Setegn, S. G. (2014). *Nile River Basin:Ecohydrological Challenges, Climate Change and Hydropolitics.* Springer International Publishing. https://doi.org/10.1007/978-3-319-02720-3

Sohom, M., Patrick, A. B., Abhishek, G., & Slobodan, P. S. (2017). *Water Resources Research Report: Tools for Downscaling Climate Variables: A Technical Manual:ISSN: (print) 1913-3200; (online) 1913-3219.*

UNESCO. (2013). *Climate change education; Education Sector technical notes; 2013*.

List of Publications

In Journals

Birhan Getachew and B.R.Manjunatha **(2022):Impacts of Land-Use Change on the Hydrology of LakeTana Basin, Upper Blue Nile River Basin, Ethiopia.** Global Challenges https://doi.org/1002/gch2.202200041.

Birhan Getachew and B.R.Manjunatha **(2022): Potential climate change impact assessment on the hydrology of the Lake Tana Basin, Upper Blue Nile River Basin, Ethiopia.** Physics and Chemistry of the Earth, Parts. https://doi.org/10.1016/j.pce.2022.103162

Birhan Getachew and B.R.Manjunatha **(2021): Climate change projections and trends simulated from the CMIP5 models for the Lake Tana sub-basin, the Upper Blue Nile (Abbay) Basin, Ethiopia.** Environmental challenges.https://doi.org/10.1016/j.envc.2021.100385

Birhan, Getachew; B.R.Manjunatha; H.Gangadhara Bhat (2021): **Assessing current and projected soil loss under changing land use and climate using RUSLE with Remote sensing and GIS in the Lake Tana Basin, Upper Blue Nile River Basin, Ethiopia**. The Egyptian Journal of Remote Sensing and Space Sciences. https://doi.org/10.1016/j.ejrs.2021.10.001

Birhan, Getachew; B.R. Manjunatha; H.Gangadhara Bhat (2021): **Modeling Projected impacts of climate and land use/land cover change on hydrological responses in the Lake Tana Basin, Upper Blue Nile River Basin, Ethiopia**. Journal of Hydrology: https://doi.org/10.1016/j.jhydrol.2021.125974

Birhan, Getachew; B.R. Manjunatha; H. Gangadhara Bhat (2020): **Spatio-temporal distribution of aerosol optical depth and cloud properties over Lake Tana Basin, Upper Blue Nile River Basin, Ethiopia**. Remote Sensing Applications: Society and Environment: https://doi.org/10.1016/j.rsase.2020.100401

Conferences

Birhan, Getachew; B.R. Manjunatha; H. Gangadhara Bhat (2021): **Current and projected soil loss under changing land use and climate using RUSLE with Remote sensing and GIS in the Lake Tana Basin, Upper Blue Nile River Basin, Ethiopia**. Environment and Society Conference. International Conference on Watershed Processes in the Face of Dynamic Landscapes and Climate Change. Florida International University from November 22-23, 2021.

Birhan, Getachew; B.R. Manjunatha; H. Gangadhara Bhat (2021): **Modeling Projected impacts of climate and land use/land cover change on hydrological responses in the Lake Tana Basin, Upper Blue Nile River Basin, Ethiopia.** The 1st African Graduate Students Conference (AGSC-BDU-2021) During May 28-29, 2021, Bahir Dar University, Bahir Dar, Ethiopia.

Signature of the Student
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Signature of the Supervisor
Date…….